# Inclusive Search for Anomalous Production of High-$p_T$ Like-Sign Lepton Pairs in $p\overline{p}$ Collisions at $\sqrt{s} = 1.8$ TeV

D. Acosta,[14] T. Affolder,[7] M.G. Albrow,[13] D. Ambrose,[36] D. Amidei,[27] K. Anikeev,[26] J. Antos,[1] G. Apollinari,[13] T. Arisawa,[50] A. Artikov,[11] W. Ashmanskas,[2] F. Azfar,[34] P. Azzi-Bacchetta,[35] N. Bacchetta,[35] H. Bachacou,[24] W. Badgett,[13] A. Barbaro-Galtieri,[24] V.E. Barnes,[39] B.A. Barnett,[21] S. Baroiant,[5] M. Barone,[15] G. Bauer,[26] F. Bedeschi,[37] S. Behari,[21] S. Belforte,[47] W.H. Bell,[17] G. Bellettini,[37] J. Bellinger,[51] D. Benjamin,[12] A. Beretvas,[13] A. Bhatti,[41] M. Binkley,[13] D. Bisello,[35] M. Bishai,[13] R.E. Blair,[2] C. Blocker,[4] K. Bloom,[27] B. Blumenfeld,[21] A. Bocci,[41] A. Bodek,[40] G. Bolla,[39] A. Bolshov,[26] D. Bortoletto,[39] J. Boudreau,[38] C. Bromberg,[28] E. Brubaker,[24] J. Budagov,[11] H.S. Budd,[40] K. Burkett,[13] G. Busetto,[35] K.L. Byrum,[2] S. Cabrera,[12] M. Campbell,[27] W. Carithers,[24] D. Carlsmith,[51] A. Castro,[3] D. Cauz,[47] A. Cerri,[24] L. Cerrito,[20] J. Chapman,[27] C. Chen,[36] Y.C. Chen,[1] M. Chertok,[5] G. Chiarelli,[37] G. Chlachidze,[13] F. Chlebana,[13] M.L. Chu,[1] J.Y. Chung,[32] W.-H. Chung,[51] Y.S. Chung,[40] C.I. Ciobanu,[20] A.G. Clark,[16] M. Coca,[40] A. Connolly,[24] M. Convery,[41] J. Conway,[43] M. Cordelli,[15] J. Cranshaw,[45] R. Culbertson,[13] D. Dagenhart,[4] S. D'Auria,[17] P. de Barbaro,[40] S. De Cecco,[42] S. Dell'Agnello,[15] M. Dell'Orso,[37] S. Demers,[40] L. Demortier,[41] M. Deninno,[3] D. De Pedis,[42] P.F. Derwent,[13] C. Dionisi,[42] J.R. Dittmann,[13] A. Dominguez,[24] S. Donati,[37] M. D'Onofrio,[16] T. Dorigo,[35] N. Eddy,[20] R. Erbacher,[13] D. Errede,[20] S. Errede,[20] R. Eusebi,[40] S. Farrington,[17] R.G. Feild,[52] J.P. Fernandez,[39] C. Ferretti,[27] R.D. Field,[14] I. Fiori,[37] B. Flaugher,[13] L.R. Flores-Castillo,[38] G.W. Foster,[13] M. Franklin,[18] J. Friedman,[26] I. Furic,[26] M. Gallinaro,[41] M. Garcia-Sciveres,[24] A.F. Garfinkel,[39] C. Gay,[52] D.W. Gerdes,[27] E. Gerstein,[9] S. Giagu,[42] P. Giannetti,[37] K. Giolo,[39] M. Giordani,[47] P. Giromini,[15] V. Glagolev,[11] D. Glenzinski,[13] M. Gold,[30] N. Goldschmidt,[27] J. Goldstein,[34] G. Gomez,[8] M. Goncharov,[44] I. Gorelov,[30] A.T. Goshaw,[12] Y. Gotra,[38] K. Goulianos,[41] A. Gresele,[3] C. Grosso-Pilcher,[10] M. Guenther,[39] J. Guimaraes da Costa,[18] C. Haber,[24] S.R. Hahn,[13] E. Halkiadakis,[40] R. Handler,[51] F. Happacher,[15] K. Hara,[48] R.M. Harris,[13] F. Hartmann,[22] K. Hatakeyama,[41] J. Hauser,[6] J. Heinrich,[36] M. Hennecke,[22] M. Herndon,[21] C. Hill,[7] A. Hocker,[40] K.D. Hoffman,[10] S. Hou,[1] B.T. Huffman,[34] R. Hughes,[32] J. Huston,[28] C. Issever,[7] J. Incandela,[7] G. Introzzi,[37] M. Iori,[42] A. Ivanov,[40] Y. Iwata,[19] B. Iyutin,[26] E. James,[13] M. Jones,[39] T. Kamon,[44]

1

J. Kang,[27] M. Karagoz Unel,[31] S. Kartal,[13] H. Kasha,[52] Y. Kato,[33] R.D. Kennedy,[13] R. Kephart,[13] B. Kilminster,[40] D.H. Kim,[23] H.S. Kim,[20] M.J. Kim,[9] S.B. Kim,[23] S.H. Kim,[48] T.H. Kim,[26] Y.K. Kim,[10] M. Kirby,[12] L. Kirsch,[4] S. Klimenko,[14] P. Koehn,[32] K. Kondo,[50] J. Konigsberg,[14] A. Korn,[26] A. Korytov,[14] J. Kroll,[36] M. Kruse,[12] V. Krutelyov,[44] S.E. Kuhlmann,[2] N. Kuznetsova,[13] A.T. Laasanen,[39] S. Lami,[41] S. Lammel,[13] J. Lancaster,[12] K. Lannon,[32] M. Lancaster,[25] R. Lander,[5] A. Lath,[43] G. Latino,[30] T. LeCompte,[2] Y. Le,[21] J. Lee,[40] S.W. Lee,[44] N. Leonardo,[26] S. Leone,[37] J.D. Lewis,[13] K. Li,[52] C.S. Lin,[13] M. Lindgren,[6] T.M. Liss,[20] T. Liu,[13] D.O. Litvintsev,[13] N.S. Lockyer,[36] A. Loginov,[29] M. Loreti,[35] D. Lucchesi,[35] P. Lukens,[13] L. Lyons,[34] J. Lys,[24] R. Madrak,[18] K. Maeshima,[13] P. Maksimovic,[21] L. Malferrari,[3] M. Mangano,[37] G. Manca,[34] M. Mariotti,[35] M. Martin,[21] A. Martin,[52] V. Martin,[31] M. Martínez,[13] P. Mazzanti,[3] K.S. McFarland,[40] P. McIntyre,[44] M. Menguzzato,[35] A. Menzione,[37] P. Merkel,[13] C. Mesropian,[41] A. Meyer,[13] T. Miao,[13] R. Miller,[28] J.S. Miller,[27] S. Miscetti,[15] G. Mitselmakher,[14] N. Moggi,[3] R. Moore,[13] T. Moulik,[39] M. Mulhearn,[26] A. Mukherjee,[13] T. Muller,[22] A. Munar,[36] P. Murat,[13] J. Nachtman,[13] S. Nahn,[52] I. Nakano,[19] R. Napora,[21] F. Niell,[27] C. Nelson,[13] T. Nelson,[13] C. Neu,[32] M.S. Neubauer,[26] C. Newman-Holmes,[13] T. Nigmanov,[38] L. Nodulman,[2] S.H. Oh,[12] Y.D. Oh,[23] T. Ohsugi,[19] T. Okusawa,[33] W. Orejudos,[24] C. Pagliarone,[37] F. Palmonari,[37] R. Paoletti,[37] V. Papadimitriou,[45] J. Patrick,[13] G. Pauletta,[47] M. Paulini,[9] T. Pauly,[34] C. Paus,[26] D. Pellett,[5] A. Penzo,[47] T.J. Phillips,[12] G. Piacentino,[37] J. Piedra,[8] K.T. Pitts,[20] A. Pompoš,[39] L. Pondrom,[51] G. Pope,[38] T. Pratt,[34] F. Prokoshin,[11] J. Proudfoot,[2] F. Ptohos,[15] O. Poukhov,[11] G. Punzi,[37] J. Rademacker,[34] A. Rakitine,[26] F. Ratnikov,[43] H. Ray,[27] A. Reichold,[34] P. Renton,[34] M. Rescigno,[42] F. Rimondi,[3] L. Ristori,[37] W.J. Robertson,[12] T. Rodrigo,[8] S. Rolli,[49] L. Rosenson,[26] R. Roser,[13] R. Rossin,[35] C. Rott,[39] A. Roy,[39] A. Ruiz,[8] D. Ryan,[49] A. Safonov,[5] R. St. Denis,[17] W.K. Sakumoto,[40] D. Saltzberg,[6] C. Sanchez,[32] A. Sansoni,[15] L. Santi,[47] S. Sarkar,[42] P. Savard,[46] A. Savoy-Navarro,[13] P. Schlabach,[13] E.E. Schmidt,[13] M.P. Schmidt,[52] M. Schmitt,[31] L. Scodellaro,[35] A. Scribano,[37] A. Sedov,[39] S. Seidel,[30] Y. Seiya,[48] A. Semenov,[11] F. Semeria,[3] M.D. Shapiro,[24] P.F. Shepard,[38] T. Shibayama,[48] M. Shimojima,[48] M. Shochet,[10] A. Sidoti,[35] A. Sill,[45] P. Sinervo,[46] A.J. Slaughter,[52] K. Sliwa,[49] F.D. Snider,[13] R. Snihur,[25] M. Spezziga,[45] F. Spinella,[37] M. Spiropulu,[7] L. Spiegel,[13] A. Stefanini,[37] J. Strologas,[30] D. Stuart,[7] A. Sukhanov,[14] K. Sumorok,[26] T. Suzuki,[48] R. Takashima,[19] K. Takikawa,[48] M. Tanaka,[2] M. Tecchio,[27] R.J. Tesarek,[13] P.K. Teng,[1] K. Terashi,[41] S. Tether,[26] J. Thom,[13]

A.S. Thompson,[17] E. Thomson,[32] P. Tipton,[40] S. Tkaczyk,[13] D. Toback,[44] K. Tollefson,[28] D. Tonelli,[37] M. Tönnesmann,[28] H. Toyoda,[33] W. Trischuk,[46] J. Tseng,[26] D. Tsybychev,[14] N. Turini,[37] F. Ukegawa,[48] T. Unverhau,[17] T. Vaiciulis,[40] A. Varganov,[27] E. Vataga,[37] S. Vejcik III,[13] G. Velev,[13] G. Veramendi,[24] R. Vidal,[13] I. Vila,[8] R. Vilar,[8] I. Volobouev,[24] M. von der Mey,[6] R.G. Wagner,[2] R.L. Wagner,[13] W. Wagner,[22] Z. Wan,[43] C. Wang,[12] M.J. Wang,[1] S.M. Wang,[14] B. Ward,[17] S. Waschke,[17] D. Waters,[25] T. Watts,[43] M. Weber,[24] W.C. Wester III,[13] B. Whitehouse,[49] A.B. Wicklund,[2] E. Wicklund,[13] H.H. Williams,[36] P. Wilson,[13] B.L. Winer,[32] N. Wisniewski,[6] S. Wolbers,[13] M. Wolter,[49] M. Worcester,[6] S. Worm,[43] X. Wu,[16] F. Würthwein,[26] U.K. Yang,[10] W. Yao,[24] G.P. Yeh,[13] K. Yi,[21] J. Yoh,[13] T. Yoshida,[33] I. Yu,[23] S. Yu,[36] J.C. Yun,[13] L. Zanello,[42] A. Zanetti,[47] F. Zetti,[24] and S. Zucchelli[3]

(CDF Collaboration)

[1] *Institute of Physics, Academia Sinica, Taipei, Taiwan 11529, Republic of China*

[2] *Argonne National Laboratory, Argonne, Illinois 60439*

[3] *Istituto Nazionale di Fisica Nucleare, University of Bologna, I-40127 Bologna, Italy*

[4] *Brandeis University, Waltham, Massachusetts 02254*

[5] *University of California at Davis, Davis, California 95616*

[6] *University of California at Los Angeles, Los Angeles, California 90024*

[7] *University of California at Santa Barbara, Santa Barbara, California 93106*

[8] *Instituto de Fisica de Cantabria, CSIC-University of Cantabria, 39005 Santander, Spain*

[9] *Carnegie Mellon University, Pittsburgh, Pennsylvania 15213*

[10] *Enrico Fermi Institute, University of Chicago, Chicago, Illinois 60637*

[11] *Joint Institute for Nuclear Research, RU-141980 Dubna, Russia*

[12] *Duke University, Durham, North Carolina 27708*

[13] *Fermi National Accelerator Laboratory, Batavia, Illinois 60510*

[14] *University of Florida, Gainesville, Florida 32611*

[15] *Laboratori Nazionali di Frascati, Istituto Nazionale di Fisica Nucleare, I-00044 Frascati, Italy*

[16] *University of Geneva, CH-1211 Geneva 4, Switzerland*

[17] *Glasgow University, Glasgow G12 8QQ, United Kingdom*

[18] *Harvard University, Cambridge, Massachusetts 02138*

[19] *Hiroshima University, Higashi-Hiroshima 724, Japan*

[20] *University of Illinois, Urbana, Illinois 61801*

[21] *The Johns Hopkins University, Baltimore, Maryland 21218*

[22] *Institut für Experimentelle Kernphysik, Universität Karlsruhe, 76128 Karlsruhe, Germany*

[23] *Center for High Energy Physics: Kyungpook National University, Taegu 702-701; Seoul National University, Seoul 151-742; and SungKyunKwan University, Suwon 440-746; Korea*

[24] *Ernest Orlando Lawrence Berkeley National Laboratory, Berkeley, California 94720*

[25] *University College London, London WC1E 6BT, United Kingdom*

[26] *Massachusetts Institute of Technology, Cambridge, Massachusetts 02139*

[27] *University of Michigan, Ann Arbor, Michigan 48109*

[28] *Michigan State University, East Lansing, Michigan 48824*

[29] *Institution for Theoretical and Experimental Physics, ITEP, Moscow 117259, Russia*

[30] *University of New Mexico, Albuquerque, New Mexico 87131*

[31] *Northwestern University, Evanston, Illinois 60208*

[32] *The Ohio State University, Columbus, Ohio 43210*

[33] *Osaka City University, Osaka 588, Japan*

[34] *University of Oxford, Oxford OX1 3RH, United Kingdom*

[35] *Universita di Padova, Istituto Nazionale di Fisica Nucleare, Sezione di Padova, I-35131 Padova, Italy*

[36] *University of Pennsylvania, Philadelphia, Pennsylvania 19104*

[37] *Istituto Nazionale di Fisica Nucleare, University and Scuola Normale Superiore of Pisa, I-56100 Pisa, Italy*

[38] *University of Pittsburgh, Pittsburgh, Pennsylvania 15260*

[39] *Purdue University, West Lafayette, Indiana 47907*

[40] *University of Rochester, Rochester, New York 14627*

[41] *Rockefeller University, New York, New York 10021*

[42] *Instituto Nazionale de Fisica Nucleare, Sezione di Roma, University di Roma I, "La Sapienza," I-00185 Roma, Italy*

[43] *Rutgers University, Piscataway, New Jersey 08855*

[44] *Texas A&M University, College Station, Texas 77843*

[45] *Texas Tech University, Lubbock, Texas 79409*

[46] *Institute of Particle Physics, University of Toronto, Toronto M5S 1A7, Canada*

[47] *Istituto Nazionale di Fisica Nucleare, University of Trieste/Udine, Italy*

[48] *University of Tsukuba, Tsukuba, Ibaraki 305, Japan*

[49] *Tufts University, Medford, Massachusetts 02155*

$^{50}$ *Waseda University, Tokyo 169, Japan*

$^{51}$ *University of Wisconsin, Madison, Wisconsin 53706*

$^{52}$ *Yale University, New Haven, Connecticut 06520*

## Abstract

We report on a search for anomalous production of events with at least two charged, isolated, like-sign leptons with $p_T > 11$ GeV/$c$ using a 107 pb$^{-1}$ sample of 1.8 TeV $p\overline{p}$ collisions collected by the CDF detector. We define a signal region containing low background from Standard Model processes. To avoid bias, we fix the final cuts before examining the event yield in the signal region using control regions to test the Monte Carlo predictions. We observe no events in the signal region, consistent with an expectation of $0.63^{+0.84}_{-0.07}$ events. We present 95% confidence level limits on new physics processes in both a signature-based context as well as within a representative minimal supergravity ($\tan\beta = 3$) model.

Numerous attempts to resolve theoretical problems with the standard model (SM) require the existence of new particles with masses at the electroweak scale, $\sim 100$ GeV$/c^2$ [1, 2, 3]. A productive method of searching for new particles at this scale has been to search for lepton production at $p\overline{p}$ colliders with high momentum transverse to the beam axis ($p_T$). Such searches led to the discovery of the $W$ and $Z$ bosons at the CERN $Sp\overline{p}S$ and to the discovery of the $t$ quark at the Fermilab Tevatron. Recently, searches for anomalous high-$p_T$ lepton production have been used to constrain supersymmetric extensions to the SM. For example, production of charginos ($\tilde{\chi}^{\pm}$) and neutralinos ($\tilde{\chi}^0$) were constrained by searches for events with three high-$p_T$ leptons [4, 5]. Limits on gluino production were likewise placed by searching for events with two like-sign leptons, two jets, and transverse energy imbalance, $\not{E}_T$ [6, 7]. These analyses achieved the necessary suppression of background processes by requiring three or more reconstructed objects in the final state and constraints on their kinematical properties.

In this Letter we present a search for new particles with masses at the electroweak scale using a minimal number of required objects or kinematical cuts. Specifically, we search for two like-sign, isolated leptons in the final state, but do not require any other objects or $\not{E}_T$. We define a signal region with less than one event expected from SM background but broad acceptance for typical models of new particle production resulting in like-sign signatures [8, 9, 10]. To avoid bias, we fix the final cuts before examining the event yield in the signal region [11].

We examine 107 pb$^{-1}$ of data collected by the Collider Detector at Fermilab (CDF) during the 1992-95 data run of the Tevatron. The CDF detector [12] is an azimuthally and forward-backward symmetric solenoidal detector designed to study $p\overline{p}$ reactions at the Tevatron. A time projection chamber measures the distance of the $p\overline{p}$ collision event vertex ($z_{vertex}$) from the center of the detector along the beam direction. The central tracking chamber (CTC) measures the trajectories of charged particles traversing a uniform 1.4 T magnetic field with a resolution of $\delta p_T/p_T^2 = 8 \times 10^{-4}$ (GeV$/c$)$^{-1}$. Outside the solenoid, a lead/scintillator central electromagnetic sampling calorimeter detects electromagnetic showers with an energy resolution of $13.5\%/\sqrt{E \sin\theta} \oplus 2\%$. Steel/scintillator hadronic calorimeters directly behind the electromagnetic calorimeters measure the hadronic component of deposited energy. Drift chambers located behind the steel detect muon candidates with momenta above 3 GeV$/c$.

We begin with a sample of 457,478 loosely selected dilepton events [13]. We select candi-

date events in a manner similar to previous CDF trilepton searches [5]. We identify charged leptons as electrons or muons each with $p_T > 11$ GeV/$c$ using the "strict" selection criteria of those analyses. As in the previous analyses, we remove events consistent with photon conversions or cosmic rays. We reject background where one lepton is a partner of known resonances by removing events consistent with any $\psi$, $\Upsilon(1S)$, or $Z$ resonance. We require $|z_{vertex}| < 60$ cm and $|z_{lepton} - z_{vertex}| < 5$ cm for each lepton, to ensure that both leptons came from the same primary collision and are well measured. We identify the two highest-$p_T$ leptons with like-sign charges as the like-sign (LS) dilepton pair. To reduce background from back-to-back QCD dijet events in which both jets are misidentified as leptons, we require the lepton pair to have vector sum transverse momentum of $p_T^{\ell\ell} > 20$ GeV/$c$ and invariant mass of $m_{\ell\ell} > 10$ GeV/$c^2$.

One notable difference from previous analyses is a modification to the lepton isolation variable ($ISO$) which separates leptons from jets. $ISO$ is the scalar sum of the transverse energy ($E_T$) measured in each calorimeter cell, $\sum E_T$, added in quadrature to the scalar sum of the $p_T$ measured in the CTC, $\sum p_T$, within a cone $\Delta R \equiv \sqrt{(\Delta\phi)^2 + (\Delta\eta)^2} = 0.4$ of each lepton candidate. The energy of the lepton candidate is removed from the $ISO$ sum by subtracting the $p_T$ of the lepton candidate track, $p_T^{cand}$, and the calorimeter $E_T$ of the lepton candidate, $E_T^{cand}$, from $\sum p_T$ and $\sum E_T$, respectively,

$$ISO = \sqrt{(\sum E_T - E_T^{cand})^2 + (\sum p_T - p_T^{cand})^2}. \tag{1}$$

$E_T^{cand}$ is the scalar sum of the $E_T$ in the calorimeter cell to which we extrapolate the lepton candidate track (the "seed" cell) and the two cells adjacent to either side of the seed cell in $\eta$ to account for lateral energy leakage between cells: $E_T^{cand} = E_T^{seed} + E_T^{leakage}$. In this analysis we have changed $E_T^{leakage}$ so that the lepton is excised from $\sum E_T$ more effectively by modeling the energy leakage between cells in greater detail [14]. In addition to the usual cut at $ISO_{\Delta R=0.4} < 2$ GeV we have added a cut on an identically defined $ISO$ cone with radius of 0.7, $ISO_{\Delta R=0.7} < 7$ GeV. The combination of double-cone cut and redefined $E_T^{leakage}$ is the "new" $ISO$.

To evaluate the efficacy of the new $ISO$ cut we demonstrate an increased separation of lepton signal from background from jets misidentified as leptons with the new $ISO$. We select leptons from 1255 $Z \to e^+e^-$ and 1389 $Z \to \mu^+\mu^-$ events with no $ISO$ requirement on the leptons. From bias-removed jet control samples with 20 and 50 GeV thresholds on

the jet $E_T$ we select a sample of 292 (237) jets passing all the LS dilepton analysis electron (muon) identification requirements except $ISO$. Figures 1(a) and (b) compare the energy in the new $ISO_{\Delta R=0.4}$ cone between the lepton and jet samples for electrons and muons, respectively. Figures 1(c) and (d) show efficiency ($\epsilon$) for electrons and muons, respectively, from the $Z \to \ell^+\ell^-$ samples as a function of $\epsilon$ for background from the jet control samples for original and new $ISO$. We generate the $\epsilon$ curves by varying the $ISO_{\Delta R=0.4}$ cut between 1 and 4 GeV within each sample. With the nominal cuts, new $ISO$ reduces background from jets being misidentified as leptons by a factor of two from the original cut while retaining the same efficiency for leptons.

Diboson production, $WZ$ and $ZZ$, where "$Z$" denotes a mixture of the $Z$ and $\gamma^*$, produces an irreducible source of SM background. Although the $Z$ resonance cut removes most of these events, some survive because the $Z$ is off-shell or we fail to find one of the leptons from the $Z$. We model this background using the Monte Carlo programs PYTHIA [15] and MCFM [16] which include off-shell contributions. The two processes contribute $0.25\pm0.09$ and $0.07\pm0.02$ events, respectively, to the signal region. The only other significant background is $W$+jets and $Z$+jets production where one of the jets is misidentified as a lepton. Because the rate of lepton misidentification is beyond the scope of the Monte Carlo programs and simulations, we anchor this calculation in the data. First, we verify that PYTHIA correctly models the observed rate of isolated tracks as a function of $p_T$ in $Z \to \ell^+\ell^-$ events, excluding the two tracks from the legs of the $Z$. Second, we use several control samples to measure the probability that such isolated tracks pass all lepton ID requirements: $(2.5 \pm 0.7)\%$ with no measurable $p_T$ dependence. Third, we multiply the PYTHIA prediction for production of a $W$ or $Z$ with an underlying isolated track by this factor to estimate backgrounds to be $0.30 \pm 0.08$ and $0.03 \pm 0.01$ events, respectively; for a complete description of this method see [17]. Using ISAJET [18] we estimate the small contribution, $0.008^{+0.006}_{-0.004}$, from $t\bar{t}$, $b\bar{b}$, and $c\bar{c}$. Finally, we set an upper limit to the contribution from events in which both lepton candidates are jets misidentified as leptons, $0.0^{+0.83}_{-0.0}$, using event yields outside the signal region. We find negligible background due to charge misassignment by using $Z$ events and track curvature studies.

We use kinematical regions having sensitivity to different background sources to test the background predictions. Events near the signal region shown in Figure 2 are compared to background predictions in Table I. The consistency of these control regions indicates the
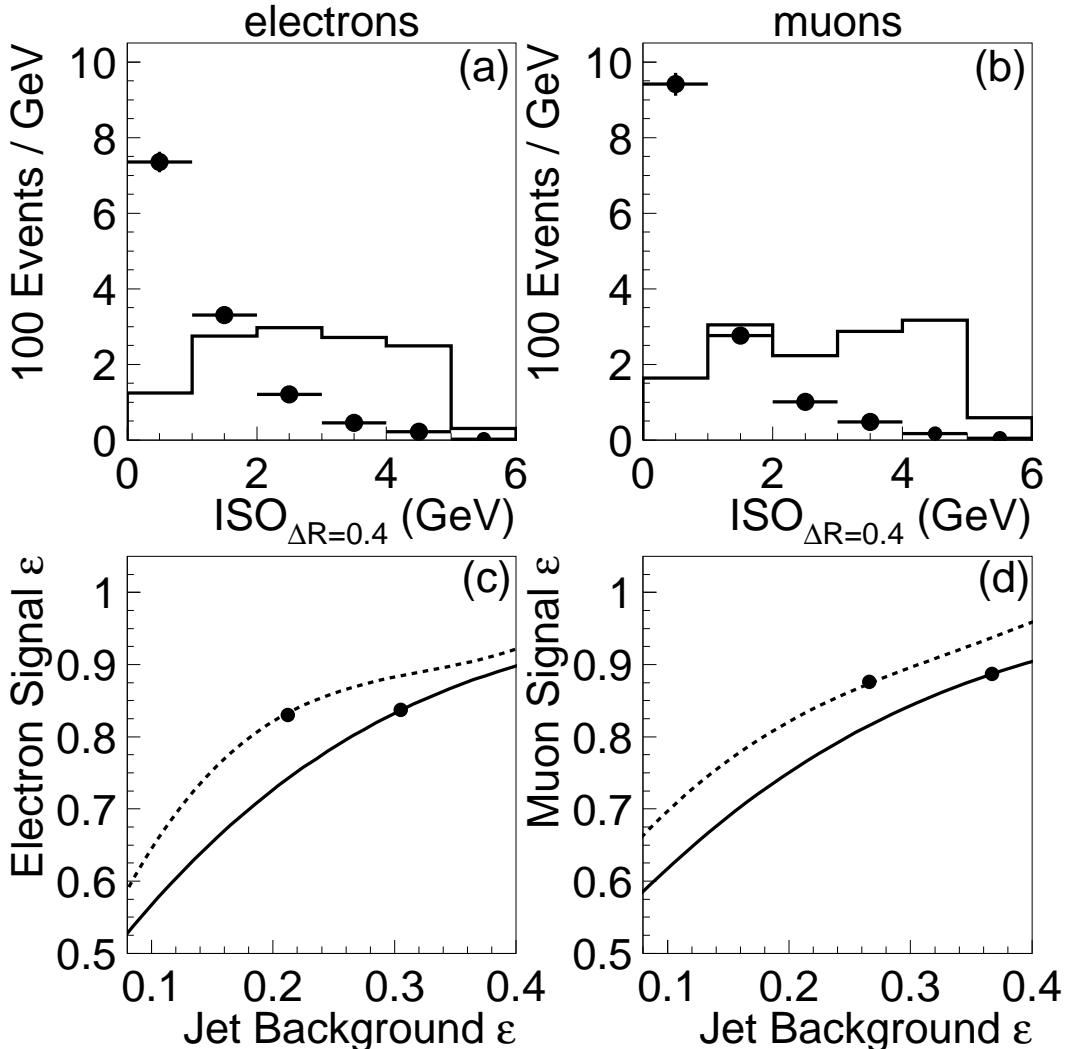
FIG. 1: (a) and (b) show the energy in the $ISO_{\Delta R=0.4}$ cone for electrons and muons, respectively, in the $Z$ dilepton dataset (points) and jet background dataset (histogram). Errors shown are statistical only. (c) and (d) show $\epsilon$ for electrons and muons, respectively, as a function of jet background $\epsilon$ for original $ISO$ (solid line) and new $ISO$ (dashed line). The markers indicate the position of the nominal original and new $ISO$ cuts on the $\epsilon$ curves.

reliability of the lepton misidentification estimates. With all the nominal cuts but the $Z$-removal cut inverted, we predict $0.11 \pm 0.03$ events and see zero. If, instead of requiring like-sign, we require an opposite-sign pair and an additional isolated $p_T > 3$ GeV/$c$ track we predict $68 \pm 9$ events and observe 62, thereby testing the Monte Carlo modeling of the effect of lost Drell-Yan leptons.

In the signal region we predict $0.63^{+0.84}_{-0.07}$ total events and observe zero. Hence this analysis
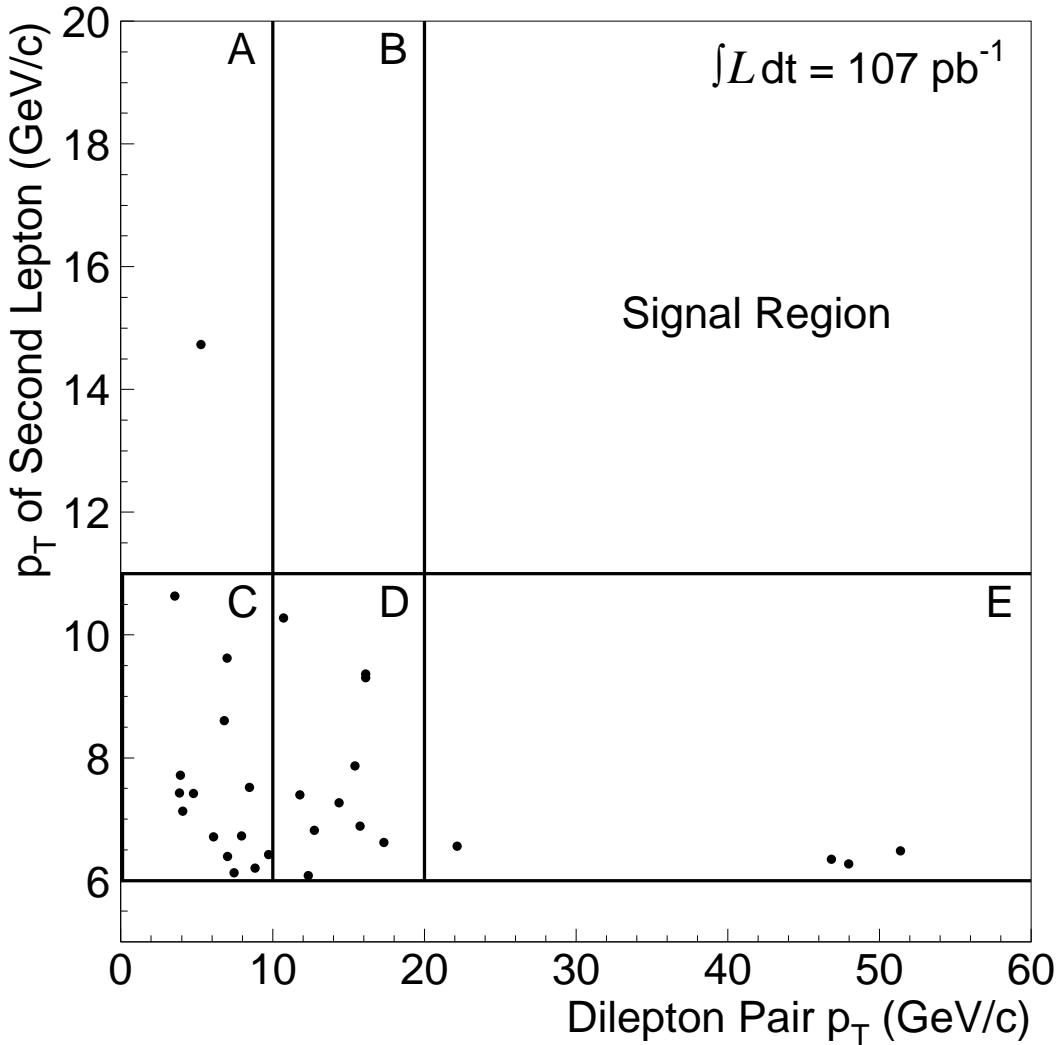
FIG. 2: Observed events in kinematical regions adjacent to the signal region; see Table I.

TABLE I: Comparison of SM background to events selected in the data in the control regions shown in Figure 2.

| Region | Background(s) | Expected background | Data |
|---|---|---|---|
| A | QCD dijet | $2.2^{+1.8}_{-1.5}$ | 1 |
| B | $WZ,ZZ$ | $0.1^{+0.9}_{-0.1}$ | 0 |
| C | QCD dijet | $19.7 \pm 8.4$ | 14 |
| D | QCD dijet | $10.0 \pm 4.5$ | 10 |
| E | $W$+jets, QCD dijet | $6.0^{+1.6}_{-1.3}$ | 4 |

provides no indication of physics beyond the SM and we proceed to set limits on new physics using a Bayesian technique [19]. Following the methodology of previous analyses, we apply sources of systematic uncertainty including trigger efficiency, luminosity, lepton ID efficiency, structure function choice, and $Q^2$ variations [5] to each model of particle production considered below.

Because we perform this search without considering any one particular model for new physics, we evaluate the result as a general limit on particle production leading to the LS dilepton signature. As an example, we generate $WZ$ pairs with PYTHIA using standard couplings and spins. However, we allow the masses of the $W$-like and $Z$-like particles to vary. After forcing the bosons to decay leptonically, we find the efficiencies range from 3% to 8% as the $W$-like and $Z$-like masses vary from 100 to 300 GeV/$c^2$. Exclusion limits on the cross section times branching ratio including a 16% systematic uncertainty are shown in Figure 3.

In addition to such signature-based limits we derive a limit within the framework of mSUGRA [20], a supergravity-inspired extension to the Minimal Supersymmetric Standard Model [3]. We take representative parameters $\tan\beta = 3$, $\mu < 0$ and $A_0 = 0$, but allow $m_0$ and $m_{1/2}$ to vary and use PYTHIA to calculate event yields. The simulation allows all particles to decay according to their calculated branching ratios so that charged leptons may be produced at any stage of cascade sparticle and particle decays. Within the context of this model, the selection is reoptimized according to the 95% confidence expected upper limit on the signal cross section, leading to an improved sensitivity by lowering the $p_T^{\ell\ell}$ cut from 20 to 10 GeV/$c^2$. In this mSUGRA model LS dilepton events are primarily produced by the decay $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0 \rightarrow \ell^{\pm}\ell^{\pm}\ell^{\mp}\tilde{\chi}_1^0\tilde{\chi}_1^0\nu$. However, this analysis is sensitive as well to LS dileptons produced in the sequential decays of squarks ($\tilde{q}$) and gluinos ($\tilde{g}$) and even to production of $\tilde{\chi}_1^{\pm}$ with $\tilde{g}$. Here the efficiency, which includes the branching ratio to leptons imposed by the model, ranges from 0.02% to 0.12%. We calculate exclusion limits on the cross section as a function of $m_0$ and $m_{1/2}$, including a 17% systematic uncertainty, to construct an excluded region in $m_0 - m_{1/2}$ space, as shown in Figure 4. We use the available next-to-leading order corrections (20%–40%) to the cross sections [21, 22]. Previous exclusions, based on $\not{E}_T$ in multijet events [23], have already covered all of this space, but with an entirely different technique.

We have shown in feasibility studies [17] that the LS dilepton signature considered here

and the previously published trilepton signatures [5] can be significantly complementary. The Run II data can be analyzed simultaneously with both techniques to obtain a sensitivity to mSUGRA space greater than either analysis alone.
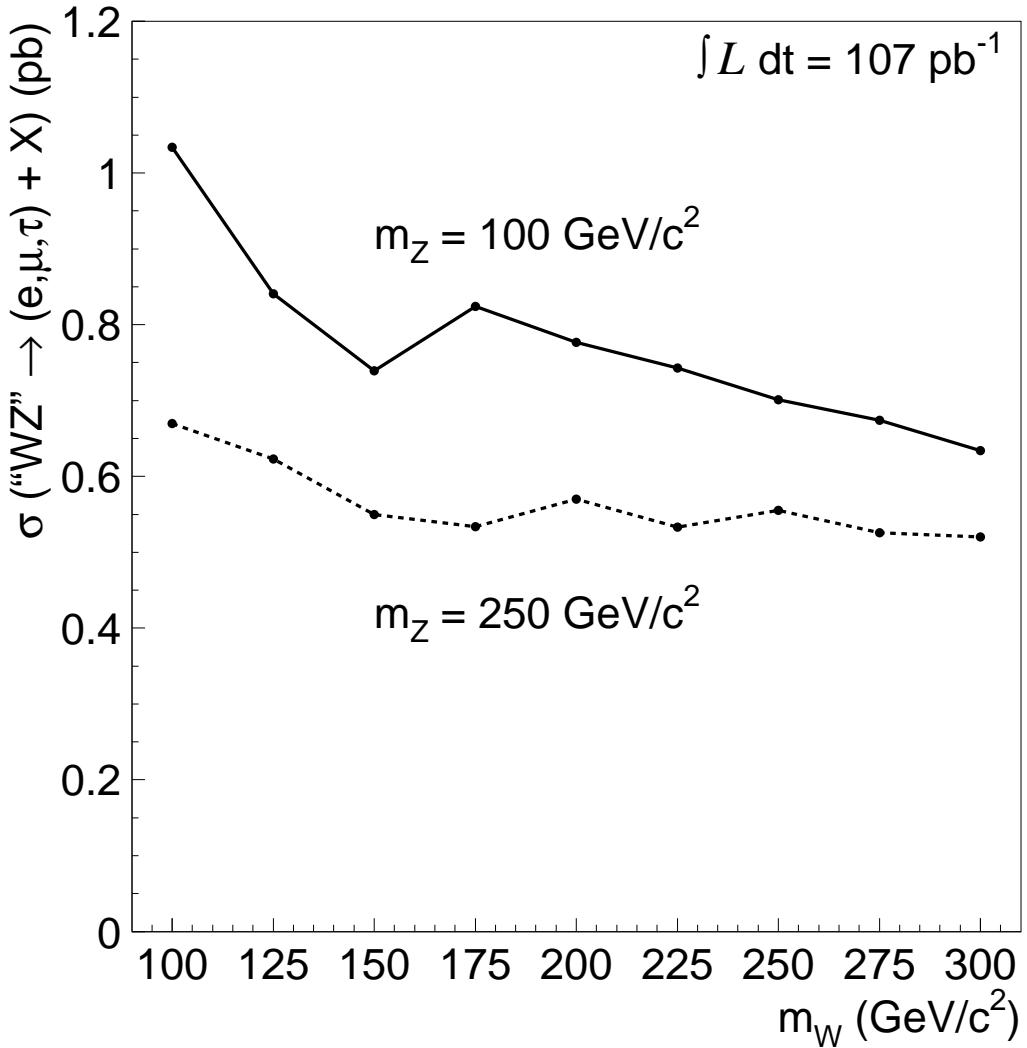
FIG. 3: The 95% confidence level limit on the cross section for "$WZ$-like" production as a function of the $W$-like particle mass, for two representative masses of the $Z$-like particle.
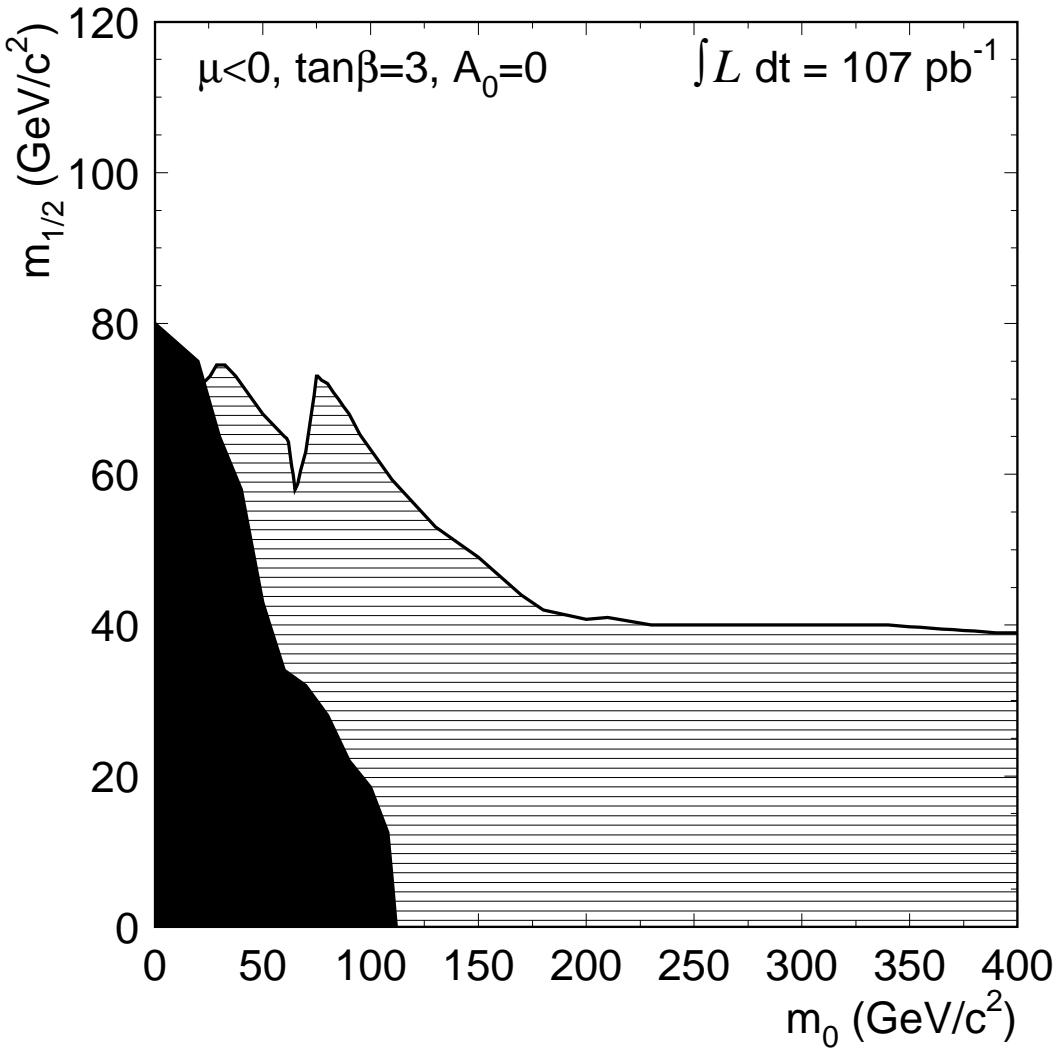
FIG. 4: The 95% confidence level limit on the parameters $m_0$ and $m_{1/2}$ in the mSUGRA framework for $\tan\beta = 3$, $\mu < 0$ and $A_0 = 0$ (hatched region). The shaded region is theoretically excluded. The dip near 75 GeV/$c^2$ results from the loss of sensitivity to the $\tilde\chi_1^\pm \tilde\chi_2^0$ signal due to decays of $\tilde\chi_1^\pm$ and $\tilde\chi_2^0$ to sneutrinos. At lower $m_0$, the limit is regained due to sensitivity to $\tilde q$ and $\tilde g$ production [20].

[1]  J. C. Pati and A. Salam, Phys. Rev. **D10**, 275 (1974).

[2]  R. D. Peccei and H. Quinn, Phys. Rev. Lett. **38**, 1440 (1977); S. Weinberg, Phys. Rev. Lett.

**40**, 223 (1978).

[3] H. P. Nilles, Phys. Rept. **110**, 1 (1984); H. E. Haber and G. I. Kane, Phys. Rept. **117**, 75 (1985).

[4] S. Abachi et al. (DØ), Phys. Rev. Lett. **76**, 2228 (1996); B. Abbott et al. (DØ), Phys. Rev. Lett. **80**, 1591 (1998).

[5] F. Abe et al. (CDF), Phys. Rev. Lett. **76**, 4307 (1996); F. Abe et al. (CDF), Phys. Rev. Lett. **80**, 5275 (1998).

[6] F. Abe et al. (CDF), Phys. Rev. Lett. **83**, 2133 (1999); F. Abe et al. (CDF), Phys. Rev. Lett. **87**, 251803 (2001).

[7] B. Abbott et al. (DØ), Phys. Rev. **D63**, 091102(R) (2001).

[8] D. B. Cline, Lett. Nuovo Cimento **41**, 518 (1984); H. Baer, X. Tata, and J. Woodside, Phys. Rev. **D41**, 906 (1990); R. M. Barnett, J. F. Gunion, and H. E. Haber, Phys. Lett. **B315**, 349 (1993).

[9] F. M. L. Almeida et al., Phys. Lett. **B400**, 331 (1997); A. Ali, A. V. Borisov, and N. B. Zamorin, Eur. Phys. J. **C21**, 123 (2001).

[10] *e.g.*, see Th. G. Rizzo, Int. J. Mod. Phys. **A11**, 1563 (1996).

[11] For a discussion of blind analyses, see P. F. Harrison, J. Phys. **G28**, 2679 (2002).

[12] F. Abe et al. (CDF), Nucl. Instr. Meth. **A271**, 387 (1988), and references therein. CDF uses a cylindrical coordinate system with polar angle $\theta$ and azimuthal angle $\phi$ with respect to the proton beam direction ($z$-axis). We define $E_T = E \sin\theta$ and $p_T = p \sin\theta$ where $E$ is an energy measured in the calorimeter and $p$ is a momentum measured by the spectrometer. Pseudorapidity is defined as $\eta = -\ln(\tan(\theta/2))$.

[13] J. P. Done, Ph.D. thesis, Texas A&M University (1999).

[14] M. Worcester, Ph.D. thesis, UCLA (2004).

[15] T. Sjöstrand, L. Lönnblad, and S. Mrenna, hep-ph/0108264 (2001), we use v. 6.157.

[16] J. M. Campbell, hep-ph/0105226 (2001).

[17] M. Worcester, J. Nachtman, and D. Saltzberg (CDF), Int. J. Mod. Phys. **A16S1B**, 797 (2001).

[18] F. Paige et al., hep-ph/9810440 (1998), we use v. 7.20.

[19] J. Conway, in *Proceedings of 1st Workshop on Confidence Limits* (Geneva, Switzerland, 2000).

[20] For more details on experimental signatures of representative mSUGRA models, see S. Abdullin et al. (CMS), J. Phys. **G28**, 469 (2002); V. Krutelyov et al., Phys. Lett. **B505**, 161

(2001).

[21] W. Beenakker, R. Hopker, and M. Spira, hep-ph/9611232 (1996).

[22] T. Plehn, private communication.

[23] F. Abe et al. (CDF), Phys. Rev. Lett. **76**, 2006 (1996); F. Abe et al. (CDF), Phys. Rev. Lett. **88**, 041801 (2002); B. Abbott et al. (DØ), Phys. Rev. Lett. **83**, 4937 (1999).